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**ANALYSIS OF COMMERCIAL ACTIVITY  
IN PHOTOVOLTAICS**

**PREPARED FOR:**

Efficiency and Alternative Energy Technology Branch  
Energy, Mines and Resources Canada  
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# *Executive Summary*

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## ***Introduction***

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Peat Marwick was commissioned to undertake a market study of the photovoltaic industry in Canada. This study aimed at developing a profile of the commercial activity in photovoltaics and providing a description of key world trends on research, market opportunities and public policy.

## ***Methodology***

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The study was undertaken in four steps:

- A planning phase using expert opinion.
- A commercial activity survey mailed out to 22 respondents.
- A qualitative survey administered to a sub-set of 22 respondents.
- A review of recent and key literature.

## ***Limitations to Results Reported***

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The commercial activity survey was only answered by 11 of the 22 respondents. Our estimates of commercial activity could suffer from non-response bias. We have provided estimates of commercial activity to the best of our ability combining our knowledge of industry activity with the results reported by the respondents.

## ***Activities of Firms in the Canadian Photovoltaic Industry***

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The results of the survey indicate that manufacturing constitutes a primary activity for only 9% of the firms, whereas assembling and distribution are each carried out by 27% of the firms, respectively. This is to be expected given the knowledge that the focus of the Canadian PV industry is not on manufacture.

knowledge that the focus of the Canadian PV industry is not on manufacture. The profile also indicated that most firms undertook more than one activity, e.g., distributing and assembling, manufacturing and assembling, etc.

The overall commercial activity of the Canadian Photovoltaic industry in the year 1987-1988 was estimated using survey results. The dollar sales were valued at 13 to 14 million dollars of which exports constituted about 6 to 6.5 million dollars (46%). Of the different activities, distribution accounted for 7 to 8 million dollars, assembling accounted for 2.8 million dollars and manufacturing accounted for 2.3 million dollars. Due to lack of sufficient data points, no further breakdown of this estimate was possible, e.g., the breakdown between manufactured modules sales and the rest.

In terms of Peak Watts (Wp), the activity of the Canadian PV industry was estimated at 400,000 Wp. Sales activity in peak watts was also estimated by applications, for example, communications accounted for 59% of the Wp followed by residential and remote lighting applications (20.3%) and retail applications (13.8%). The rest of the sales was for monitoring/sensing applications (2%) and water pumping (4.9%).

The commercial activity estimated by us on the basis of the commercial activity survey is somewhat similar to the estimates given by industry participants in the qualitative survey (industry participants estimated the commercial activity at 300 KWp and ten million dollar in sales). Based on their assumptions of today's market size, respondents to the qualitative survey estimated the Canadian PV market in the year 2000 to be in the order of 40 to 50 million dollars. This projection assumed appropriate industry initiatives and public policy.

### ***Research Trends and Technological Options***

The respondents to the qualitative survey (n=12) were quite aware of world trends in cell research. They expressed a strong opinion that Canada should closely monitor improvements in cell technology in order to keep up with competition in the world markets and produce advanced PV systems at low cost.

The respondents to the qualitative survey unanimously agreed that the Canadian government should support applied research in photovoltaics. Of course, some respondents (28%) felt that it would be worthwhile for the government to support some fundamental (pure) research as well.

## ***Market Trends***

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The respondents to the qualitative survey were quite aware of world markets and PV applications. They were also aware of the strengths and weaknesses of the Canadian PV industry. In the light of world market trends and the competitive advantage of the Canadian PV industry, the following applications were ranked in order of potential growth in future years:

- PV/Diesel Hybrid (Rank 1)
- Communications (Rank 2)
- Off-the-grid rural (Rank 3)
- Off-the-grid residential (Rank 4)
- Consumer products (Rank 5)
- Grid-connected residential (Rank 6)
- Central-station (Rank 7).

## ***Industry Initiatives***

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With respect to proactive measures to be adopted by the industry, the qualitative survey respondents suggested niche marketing, focus on applications suited for specific environments, and improved communications between researchers, developers, industry participants, the government and agencies. Systematic collection of information on Canadian PV experience and dissemination of such information was considered vital. Promotions aimed at the Canadian government and Export Markets were also deemed very important from a strategic perspective.

## ***Government Initiatives***

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In addition to a strategic plan for the industry, the qualitative survey respondents also suggested various measures to be followed by the government:

- Development of a strategic framework in consultation with the industry.
- Research and buying support to specific applications identified as vital to the growth and survival of the Canadian PV industry.
- Proactive promotion of Canadian PV experience in world markets.
- Education of government personnel and the Canadian Public on the environmental advantages of PV applications.

### **Export Markets for Canadian PV Applications/Products**

The export markets for Canadian PV applications/products would be highly dependent on the price and performance of the industry's outputs as well as on the level of promotions and distribution channels available for world market penetration. The qualitative survey participants felt that, currently, prices were higher and that service quality was good although limited in terms of scope and variety. Despite current drawbacks, it was felt that the communications, remote lighting and pumping applications would give the Canadian Industry a good chance in major world markets such as Africa, Northern Countries, South East Asia, Caribbean, Polynesia, Central America, U.S.A. and Europe.

The importance of using Canadian embassies, the Export Development Corporation and CIDA as points of contact for export market developments was also emphasized by the respondents to the qualitative survey.

### **International Markets and Trends**

A review of recent and key literature on international markets and trends indicates that PV module and installed systems costs will be considerably lower by the year 2000. On the basis of environmental and price advantages, PV technology will be widely adopted by various countries for telecommunications, telemetry, cathodic protection, pumping, rural off-the-grid and diesel replacement applications. The total world market for PV modules in the year 2000 is estimated at 195 MWp under "status quo" assumptions and at 440 MWp under an accelerated scenario. The world market for PV is expected to be strong and healthy.

### Introduction

---

La société Peat Marwick a reçu mission de faire une étude de marché concernant l'industrie de l'énergie photovoltaïque au Canada. L'étude avait pour but de dresser un tableau de l'activité commerciale dans le secteur de l'énergie photovoltaïque et de décrire les principales tendances qui se manifestent à l'échelle mondiale sur le plan de la recherche, des marchés et des mesures d'intérêt public.

### Méthodologie

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L'étude comprenait quatre volets, à savoir :

- une étape de planification au cours de laquelle des spécialistes ont été consultés;
- un questionnaire d'enquête sur l'activité commerciale, qui a été envoyé à 22 entreprises;
- un questionnaire d'enquête qualitative qui a été distribué à un sous-échantillon de 22 entreprises et
- une étude des documents les plus récents et importants ayant trait au domaine de l'énergie photovoltaïque.

### Limites des résultats

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Seulement 11 des 22 entreprises auxquelles nous avons demandé de participer à l'enquête sur l'activité commerciale ont répondu au questionnaire. Il est donc possible que nos estimations concernant l'activité commerciale souffrent de biais dû à la non-réponse. Nous avons fait de notre mieux pour produire ces estimations en combinant ce que nous savons des activités de l'industrie et les réponses fournies par les participants.

## Activités des entreprises faisant partie de l'industrie canadienne de l'énergie photovoltaïque

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Les résultats de l'enquête montrent que seulement 9 % des entreprises se livrent principalement à des activités de fabrication, tandis que 27 % des entreprises se spécialisent dans l'assemblage et un autre 27 % s'occupe surtout de distribution. Cette répartition n'a pas de quoi surprendre puisque l'on sait que l'industrie canadienne de l'énergie photovoltaïque ne concentre pas ses efforts sur la fabrication. Les résultats relèvent également que la plupart des entreprises se livrent à plus d'un genre d'activités à la fois : par exemple, elle s'intéressent à la distribution et à l'assemblage, à la fabrication et à l'assemblage, etc.

Les résultats de l'enquête ont aussi servi à estimer de façon générale l'activité commerciale au sein de l'industrie canadienne de l'énergie photovoltaïque en 1987-1988. Les ventes réalisées au cours de l'année à l'étude ont été évaluées à entre 13 et 14 millions de dollars; la valeur des ventes à l'exportation était d'environ 6 à 6,5 millions de dollars, soit 46 % du total. Par ailleurs, on peut ajouter que la valeur des activités de distribution s'est élevée à 7 à 8 millions de dollars, contre 2,8 millions de dollars pour le secteur de l'assemblage et 2,3 millions de dollars pour celui de la fabrication. En raison du manque de données, il n'a pas été possible de faire une ventilation plus complète des ventes, par exemple, de distinguer les ventes de modules préfabriqués du reste.

En termes de watts-crête (Wp), l'activité de l'industrie canadienne de l'énergie photovoltaïque a été évaluée à 400 000 Wp. Nous avons également estimé les ventes en watts-crête par champ d'application : par exemple, le domaine des communications représentait 59 % du total, suivi du secteur résidentiel et des systèmes d'éclairage dans les régions éloignées (20,3 %) et du secteur commercial (13,8 %). Le reste des systèmes vendus était destiné à des activités de surveillance ou de captage (2 %) et au pompage de l'eau (4,9 %).

Les estimations que nous avons réalisées à partir des résultats de l'enquête sur l'activité commerciale ressemblent quelque peu à celles que les participants de l'industrie nous ont fourni dans le cadre de l'enquête qualitative (les participants ont estimé que l'activité commerciale s'était élevée à 300 000 Wp et que les ventes avaient atteint 10 millions de dollars). En se fondant sur leur perception de l'ampleur du marché actuel, les entreprises qui ont répondu à l'enquête qualitative ont estimé que la valeur du marché canadien de l'énergie photovoltaïque serait de l'ordre de 40 à 50 millions de dollars en l'an 2000. Pour faire cette prévision, les participants ont supposé que

l'industrie prendrait certaines initiatives appropriées et que des mesures pertinentes d'intérêt public seraient adoptées.

#### Tendances de la recherche et solutions technologiques

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Les participants à l'enquête qualitative (n = 12) étaient fort bien renseignés au sujet des grandes tendances mondiales dans la recherche sur les cellules photovoltaïques. Ils ont souligné avec force que le Canada devrait surveiller de près les améliorations qui sont apportées à la technologie des cellules afin de demeurer concurrentiel sur les marchés mondiaux et de pouvoir produire des systèmes photovoltaïques perfectionnés à peu de frais.

Ces mêmes participants ont unanimement déclaré que le gouvernement du Canada devrait soutenir la recherche appliquée dans le domaine de l'énergie photovoltaïque. Certains participants (28 %) sont évidemment d'avis qu'il serait profitable que le gouvernement appuie également certaines activités de recherche fondamentale.

#### Tendances du marché

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Les entreprises qui ont participé à l'enquête qualitative étaient fort bien renseignées au sujet des marchés internationaux et des applications dans le domaine des systèmes photovoltaïques. Elles connaissaient bien aussi les points forts et les faiblesses de l'industrie canadienne. Compte tenu des tendances du marché mondial et de l'avantage concurrentiel dont le Canada bénéficie, on a évalué dans quelle mesure certains secteurs d'utilisation pourraient connaître un essor dans l'avenir. Cet exercice a produit le classement suivant :

- les systèmes hybrides de cellules photovoltaïques et de génératrices diesel (1<sup>er</sup> rang);
- les communications (2<sup>e</sup> rang);
- la production d'électricité en milieu rural non desservi par un réseau (3<sup>e</sup> rang);
- la production d'électricité en milieu résidentiel non desservi par un réseau (4<sup>e</sup> rang);
- les produits grand-public (5<sup>e</sup> rang);

- la production d'électricité en milieu résidentiel desservi par un réseau (6<sup>e</sup> rang) et
- les stations centrales (7<sup>e</sup> rang).

#### Initiatives de l'industrie

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Les participants à l'enquête qualitative ont également proposé certaines mesures proactives que l'industrie pourrait adopter : axer la commercialisation sur certains créneaux, concentrer les efforts sur les applications qui conviennent bien à des milieux particuliers et améliorer la communication entre les chercheurs, les entrepreneurs, les membres de l'industrie et les responsables des gouvernements et des organismes. Les participants sont d'avis qu'il est essentiel de recueillir systématiquement de l'information sur les activités de l'industrie canadienne de l'énergie photovoltaïque et de diffuser cette information. Ils ont aussi souligné l'importance, sur le plan stratégique, d'entreprendre des campagnes de promotion dirigées vers le gouvernement canadien et les marchés d'exportation.

#### Initiatives de gouvernement

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En plus de recommander qu'un plan stratégique soit élaboré pour l'industrie de l'énergie photovoltaïque, les entreprises qui ont répondu à l'enquête qualitative ont suggéré au gouvernement de prendre les mesures suivantes :

- élaborer un cadre de stratégie, en consultation avec l'industrie;
- mener des activités de recherche et de développement relativement à certaines applications que l'on juge vitales à la croissance et à la survie de l'industrie canadienne de l'énergie photovoltaïque;
- entreprendre de façon proactive des démarches visant à promouvoir sur les marchés internationaux l'expérience acquise au Canada dans le domaine de l'énergie photovoltaïque et
- renseigner les fonctionnaires et le public canadien au sujet des avantages que l'énergie photovoltaïque présente sur le plan environnemental.

## Les marchés d'exportation des produits de l'industrie canadienne de l'énergie photovoltaïque

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Le succès des produits canadiens sur les marchés étrangers dépendra beaucoup de leur prix et de leur rendement ainsi que de l'intensité des activités de promotion et du nombre de voies de distribution permettant de pénétrer les marchés à l'étranger. Les participants à l'enquête qualitative croient que les prix sont élevés à l'heure actuelle et que le service est de bonne qualité, bien que les possibilités et la diversité soient restreintes à cet égard. Malgré ces faiblesses actuelles, les participants sont d'avis que les applications relatives aux communications, à l'éclairage dans les régions éloignées et au pompage pourraient donner à l'industrie canadienne de bonnes chances de faire une percée sur de gros marchés étrangers comme ceux de l'Afrique, des pays du Nord, du sud-est de l'Asie, des Antilles, de la Polynésie, de l'Amérique Centrale, des États-Unis et de l'Europe,

Les participants ont aussi souligné le rôle important que les ambassades canadiennes, le Société pour l'expansion des exportations et l'ACDI peuvent jouer en tant que points de contact pour des activités visant à développer les marchés d'exportation.

## Étude des marchés et des tendances à l'échelle internationale

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Après examen des documents les plus récents et importants traitant des marchés et des tendances à l'échelle internationale, on peut conclure que le coût des modules photovoltaïques et des systèmes installés diminuera considérablement d'ici l'an 2000. En raison des avantages qu'elle offre sur les plans environnemental et financier, la technologie de l'énergie photovoltaïque deviendra très répandue dans divers pays qui l'utiliseront pour les télécommunications, la télémetrie, la protection cathodique, le pompage, la production d'électricité en milieu rural non desservi par un réseau et le remplacement des génératrices diesel. On estime qu'en l'an 2000, l'ensemble du marché mondial pour les modules photovoltaïques sera de 195 MWp si les conditions actuelles se maintiennent et de 440 MWp si les conditions favorisent une croissance plus rapide dans ce domaine. On prévoit que le marché mondial de l'énergie photovoltaïque sera dynamique et prospère.



# *I - Study Objectives, and Methodology*

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The photovoltaic (PV) industry in Canada is highly concentrated with a limited number of players in manufacturing, distribution, installation, research and development and other related areas. For purposes of government policy and decision-making, it was considered important to generate a commercial activity profile of the industry.

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## *Study Objectives*

Peat Marwick was commissioned to undertake a market study which had two key objectives:

1. The development of an industry activity profile which will focus on the modules, systems and Balance of Systems (BOS) sales for users within Canada and outside Canada.
2. An analysis of world trends on research, market opportunities and public policy.

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## *Methodology*

Peat Marwick proposed to undertake this study in four steps:

1. A **planning phase** in which several industry advisors would be contacted in person or by telephone to facilitate the development of a data collection framework and a complete list of commercially active participants in the industry to whom a survey is to be mailed out.
2. A **commercial activity survey** which would be mailed out to commercially active firms in the industry.
3. Enhancements to the findings of the commercial activity survey through a **qualitative survey** on world and Canadian research, market and policy trends.

4. A review of recent and key literature to summarize world market trends in the photovoltaic industry.

### **Planning Phase**

The planning phase involved extensive consultations with 13 industry representatives, NGO's and government representatives. At the end of this stage, a questionnaire was developed (a separate Addendum to the report) to capture the key information required for the study. Also, a list of commercially active industry participants relevant to the survey was generated (Exhibit I-1, overleaf).

### **Commercial Activity Survey**

The commercial activity survey was mailed out to 22 commercially active firms. Non-responding participants were called back three to four times because it was felt that given the small size of the industry considerable bias could result from non-response. On May 23, 1989, a status report was presented to interested parties on the findings of the survey. Non-responding firms were requested to fill out the questionnaire and mail-it back. In spite of all this effort, only 11 of the 22 firms responded to the survey. The limitations imposed by the non-response are discussed in Chapter II.

### **Qualitative Survey**

The next step in this process consisted of a qualitative survey (results discussed in Chapter III) which aimed at obtaining the inputs of industry participants and experts on the world-wide trends, the relevance of these trends to Canada, and the action that the private sector and government should take in order to enable Canada to capture a sizeable share of world market opportunities in photovoltaics. The questionnaire used for this qualitative survey is a separate addendum to this report.

### **Review of Literature**

The literature review was conducted in several stages. First, a long list of relevant literature was discussed with experts in our planning phase to identify the key literature. Also, our expert advisor, Don Adkinson, provided some critical inputs. Secondly, an attempt was made to obtain the key reports and articles from libraries in U.S. and Canada. Some critical reports which were not available on inter-library loan were purchased. Lastly, the selected reports and articles were examined for the purposes of identifying market trends and

## EXHIBIT I-1

### LIST OF FIRMS SELECTED FOR MAIL-OUT SURVEY ON COMMERCIAL ACTIVITY OF THE PV INDUSTRY

- |                                                            |                                                                  |
|------------------------------------------------------------|------------------------------------------------------------------|
| 1. Contra/Entropy Company Ltd.<br>Lyons Head, Ontario      | 12. Westronic Inc.<br>Calgary, Alberta                           |
| 2. Prometheus Energy<br>Concord, Ontario                   | 13. Intersolar Group Canada<br>Pickering, Ontario                |
| 3. Tideland Signal Canada Ltd.<br>Burnaby, B.C.            | 14. Soltek Solar Energy<br>Victoria, B.C.                        |
| 4. Leonard Electric Ltd.<br>Mississauga, Ontario           | 15. Global Thermoelectric Power Systems<br>Calgary, Alberta      |
| 5. Mechtron Energy Systems<br>Ottawa, Ontario              | 16. Bestek Micro Devices & Systems<br>Ottawa, Ontario            |
| 6. Mayerson Solar Sales<br>Orleans, Ontario                | 17. Solace Micropower Engineering Ltd.<br>Vancouver, B.C.        |
| 7. Seastar Instruments<br>Sidney, B.C.                     | 18. Solarpac Energy Systems<br>Mississauga, Ontario              |
| 8. Argus Telecom International Inc.<br>St. Laurent, Quebec | 19. Silonex Inc.<br>St. Laurent, Quebec                          |
| 9. Geneq Inc.<br>Montreal, Quebec                          | 20. Ken Solar Systems<br>Chatham, Ontario                        |
| 10. Lenbrook Industries<br>Pickering, Ontario              | 21. Solar Quip Heating Systems Ltd.<br>Richards Landing, Ontario |
| 11. Photron Canada<br>Colinton, Alberta                    | 22. Astropower Canada<br>Nepean, Ontario                         |

comparing the various forecasts. Chapter IV presents the most significant market trends and those market forecasts which, in our opinion, appear to reflect the demand for PV most accurately compared to other forecasts.

A reference list of the literature reviewed and a complete bibliography of sources identified are provided as Appendix A and Appendix B, respectively.

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### ***Report Structure***

This report provides the results of the commercial activity survey in Chapter II, the qualitative survey in Chapter III, and the literature review in Chapter IV.

# *II - Commercial Activity Survey Findings*

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## ***Survey Description***

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The commercial activity survey was mailed out to 22 key participants in the industry. Since the size of the PV industry was small, no attempt was made to draw a sample. The use of telephone call-backs to non-respondents was expected to prompt most firms to send a response.

The survey was divided into three parts:

- Part I asked questions relating to the firm's activities in the photovoltaic industry, e.g., whether the firm was involved in manufacturing, assembling, distribution, retailing, wholesaling, consulting, installation, etc., the inputs to each activity, the sales generated by each activity and the percentages of sales for each activity accruing from exports.
- Part II attempted to obtain a breakdown of the sales of complete systems packages, modules sold separately from complete systems packages and the Balance of System (BOS) equipment. In this part an attempt was made to obtain information for three years in dollars and Wp (Peak Watts) and, if possible, by type of users and the regional distribution by point of end use.
- Part III aimed at obtaining opinions of respondents on important technology, market and public policy trends and issues facing the Canadian photovoltaic industry.

## ***Limitations Stemming from Non-Response***

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This chapter summarizes the results of the commercial activity survey. It is noted that the results reported in this chapter have limitations on account of non-response. Of the 22 surveys only 11 were mailed back. Whereas this fifty percent response rate would be acceptable for mail-out surveys with a

large sample, it is our opinion, that in this particular case it could potentially bias the results because of the small number of players in the industry.

The quality of information collected from the respondents was good, however, we are not sure if this sample of 11 respondents is representative of the 11 non-respondents. In other words, if the 11 respondents are similar in aggregate to the 11 non-respondents, then the estimates of our commercial activity would not suffer from non-response bias. However, if the non-responding firms did not respond because of some factor related to their commercial activity, e.g., firms currently busy in export markets did not respond, then our results could be biased.

### ***The Activities of Firms in the Canadian Photovoltaic Industry***

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The photovoltaic commercial activity survey respondents indicated the areas or activities in which their firms participated. Exhibit II-1, overleaf, summarizes the results of the survey. The results indicate that of the 11 respondents, 9% are involved in manufacturing as a primary activity and another 36% are involved in manufacturing as a secondary activity. Assembling constitutes a primary activity for 27% of the firms and a secondary activity for another 27% of the firms. Distribution and retailing each constitutes a primary activity for 27% of the firms and a secondary activity for 45% of the firms. The exhibit indicates that 36% of the firms are involved in consulting as a primary and a secondary activity. With respect to installation only one firm (9%) reported this as a primary activity while 6 firms (54%) reported installation as a secondary activity.

The results indicate that the photovoltaic industry at this time includes firms who undertake more than one activity. To some extent, this is indicative of an industry which has not reached maturity at which stage specialization becomes a key characteristic. The primary activity profile (Exhibit II-1) suggests that manufacturing is under-represented in the activities (9% versus 27%). This is to be expected given the fact that the focus of the Canadian industry is more on applications of assembled products rather than on manufacture. Secondly, some manufacturing firms, in the recent past, have had difficulties in remaining commercially viable due to the small size of the domestic market.

# EXHIBIT II-1

## ACTIVITY PROFILE OF PHOTOVOLTAIC FIRMS\*

|               | Primary Activity |    | Secondary Activity |    | Primary or<br>Secondary Activity |    |
|---------------|------------------|----|--------------------|----|----------------------------------|----|
|               | #                | %  | #                  | %  | #                                | %  |
| Manufacturing | 1                | 9  | 4                  | 36 | 5                                | 45 |
| Assembling    | 3                | 27 | 3                  | 27 | 6                                | 54 |
| Distribution  | 3                | 27 | 5                  | 45 | 8                                | 72 |
| Retailing     | 3                | 27 | 5                  | 45 | 8                                | 72 |
| Wholesaling   | 3                | 27 | 4                  | 36 | 7                                | 63 |
| Consulting    | 4                | 36 | 4                  | 36 | 8                                | 72 |
| Installation  | 1                | 9  | 6                  | 54 | 7                                | 63 |
| Other         | 4                | 36 | 1                  | 9  | 5                                | 45 |

\*n = 11 firms, percentages do not add up to 100 because of multiple responses, i.e., each firm could have more than one primary and one secondary activity.

## **Overall Commercial Activity in Photovoltaics**

The overall commercial activity in the Canadian photovoltaic industry for the year 1987-1988 is estimated to be in the order of 13-14 million dollars. This estimate of ours is confirmed by three other respondents to our qualitative survey who provided estimates of the current size of the Canadian photovoltaic industry. These three respondents estimated the size of the industry today to be in the order 10 million dollars.

The overall exports to countries outside Canada are estimated to be in the order of 6.5 to 8.0 million dollars. It is also estimated that the power output of commercial activity in the Canadian Photovoltaic industry is in the order of 400 KWp. The estimates of commercial activity are summarized in Exhibit II-2, overleaf.

This estimate of commercial activity would have been far more accurate if all the respondents had mailed back their surveys. With 50% non-response in a census survey aimed at 22 participants in the photovoltaic industry, we are not sure about the level of bias.

However, we have tried our best to extrapolate the results of the survey (a sample of 11 responses) to the industry. Factors such as the activity profile of those firms that did not respond and their relative estimated size were taken into account.

## **Manufacturing**

The manufactured items reported by 5 of the 11 firms answering the commercial activity survey included:

- Photovoltaic modules.
- BOS systems components.
- PV powered water pumps.
- Energy saving lighting systems.
- Manufacturing and test equipment for photovoltaics.
- Power boards for system integration.

## EXHIBIT II-2

### ESTIMATES OF ALL ANNUAL COMMERCIAL ACTIVITY IN THE CANADIAN PHOTOVOLTAIC INDUSTRY\* FOR 1987-88

| Estimates                    | Activities    |            |              |       |            |
|------------------------------|---------------|------------|--------------|-------|------------|
|                              | Manufacturing | Assembling | Distribution | Other | Total      |
| Total (\$M)                  | 2.3           | 2.8        | 7 to 8       | 0.9   | 13 to 14   |
| Export (\$M)                 | 1 to 1.5      | 1 to 1.5   | 4 to 4.5     | 0.5   | 6.5 to 8.0 |
| For use in<br>Canada (\$M)** | 0.8 to 1.3    | 1.3 to 1.8 | 3 to 3.5     | 0.4   | 6.0 to 6.5 |

\* Estimates are in millions of dollars based on activities reported by respondents and extrapolated to the Canadian industry.

\*\* Obtained by subtracting export dollar estimates from total dollar estimates.

- DC controls and DC fuse boxes.
- Cable sets, wiring kits.
- Support structures.

All the firms stated that imported components (primarily from U.S.A.) went into the manufacturing activity. The key suppliers from U.S.A. were Photron Inc., Arco Solar, Specialty Concepts, and Trace Engineering. Some Canadian suppliers were also mentioned, especially with reference to printed circuits, bulk cable, enclosures, and conduits. One firm reported imports of components for manufacturing from Hong Kong and Germany.

The firms responding to the survey provided information on their overall revenue for the year 1987-1988 and the percentage of the sales allocable to manufacturing activities. Based on these very confidential numbers and the overall make-up of the Canadian Photovoltaic Industry, we have estimated manufacturing activities in Photovoltaics to be in the order of 2.3 million dollars<sup>1</sup> for the year 1987-1988.

In addition to providing information on the scope and value of manufacturing activities, the firms also reported on the value of export sales of manufactured items. Our analysis of this information and extrapolation using our judgment indicates that the value of exports in the area of manufacturing is in the order of 1 to 1.5 million dollars for 1987-1988.

The countries to which the manufactured products were sold included Africa, Ghana, Bahamas, U.S.A., Netherlands, Zimbabwe, India, Sri Lanka and Argentina.

This estimate indicates that domestic use of Canadian manufactured photovoltaic items is not as high as it could be. It appears that in order to facilitate the survival of Canadian manufacturers, the domestic market should be stimulated via strong marketing to government agencies and departments as well as to major private sector users in the communications, pumping and remote area lighting industries.

### **Assembling**

The following items were reported as being assembled by 6 of the 11 firms answering the commercial activity survey:

<sup>1</sup> Please read first few paragraphs of this chapter to understand data limitations.

- PV power systems.
- Total system packages.
- Power Board for systems.
- Hydro meteorological systems.
- Electronic ballasts for lamps.
- Solar control systems.
- PV panel mounts.
- Roof racks.
- Distribution wiring.

Although a majority of inputs to the assembling process included imports, some inputs used were also of Canadian origin. The key suppliers from outside Canada were reported to be Solapak, U.K., Arco, SCI, Photron and Heliotrope General from the U.S.A.

The firms responding to the survey provided information on their overall sales revenue for the year 1987-1988 and the percentage of the sales allocable to assembling activities. Based on these very confidential numbers, and a knowledge of the overall make up of the Canadian Photovoltaic Industry, we have estimated assembling activities in photovoltaics to be in the order of 2.8 million dollars for the year 1987-1988.

The firms engaged in assembling activities reported exports to Mali, African and Caribbean countries. The exports, once again, as in the case of manufacturing, are estimated to be 1-1.5 million dollars for the year 1987-88.

#### **Distribution/Wholesale/Retailing**

Of the firms in the survey reporting trade activities, 10 firms provided information on the scope and value of their distribution related activities.

The items distributed included Solar panels, PV controls, remote prime power supply systems, emergency power supply systems, power system

accessories, modules, regulators, inverters, batteries, roof racks, distribution wiring, solar panels, consumer battery chargers, etc.

The major source of supply for the distributed items was U.S.A. Suppliers mentioned in the survey included Arco Solar, BEST, SCI, Solarex, Trace Engineering, Photron, Chronar and Dytek. Solapak a supplier from U.K. and others from Hong Kong and the Far East were also mentioned in the survey.

The firms responding to the survey provided information on their overall sales revenue for the year 1987-88 and the percentage of sales allocable to distribution activities. Based on these very confidential numbers and the overall make-up of the Canadian Photovoltaic Industry, we have estimated distribution activities in photovoltaics to be in the order of 7 to 8 million dollars for the year 1987-1988.

The distributed items were exported to Africa, Trinidad, Bahamas, Tobago, Africa, the Caribbean, Mali, Mexico and Latin America. The value of the exports is estimated at 4-4.5 million dollars for 1987-88.

### ***Sales Activity by Product***

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The survey of commercial activity made a major attempt to obtain breakdown of sales revenues by complete system packages, modules sold outside system packages and balance of systems (BOS). Furthermore, sales breakdown by Peak Watts applications was requested. A summary of the results are presented in Exhibits II-3, II-4 and II-5, overleaf.

Exhibit II-3 indicates that sales of modules in and outside system packages are dominated by communication applications which account for 59.0% of the total Wp (Peak Watts) sold by the responding firms. Residential and remote lighting applications account for a 20.3% share of the total Wp sold, retail application account for 13.8% of the total Wp sold. The other applications mentioned include monitoring and sensing, and water pumping. The exhibit is self explanatory and provides the proportion of Wp used by each application. The sales in dollars by application was not estimated because of lack of data.

The survey respondents also provided a breakdown of sales of BOS by equipment type (e.g., batteries, power conditioning and other equipment). Exhibit II-4 indicates that the mix of revenues by batteries, power conditioning and other equipment varied by applications. In the case of communication applications, power conditioning accounts for 51.4% of BOS revenues while batteries and other equipment account for 25% and 23.6%,

### EXHIBIT II-3

#### DISTRIBUTION OF ANNUAL SALES ACTIVITY IN PEAK WATTS BY APPLICATION IN THE CANADIAN PHOTOVOLTAIC MARKET

| APPLICATIONS                | % PEAK WATTS* | ESTIMATED<br>Wp* |
|-----------------------------|---------------|------------------|
| Communications              | 59.0          | 236,000          |
| Monitoring/Sensing          | 2.0           | 8,000            |
| Waterpumping                | 4.9           | 19,600           |
| Residential/Remote Lighting | 20.3          | 81,200           |
| Retail and Other            | 13.8          | 55,200           |
|                             | <hr/>         | <hr/>            |
|                             | 100.0         | 400,000          |

\* n = 11. Percent of Total Wp (Peak Watts) reported over all applications for modules in and outside complete systems packages. The percentage distribution is based on the responses received. The Wp per application was derived from the overall power output of commercial activity estimated at 400 KWp.

**EXHIBIT II-4**

**REVENUES FOR BOS BY APPLICATIONS**

|                | <b>Batteries</b> | <b>Power Conditioning</b> | <b>Other</b> | <b>Total</b> |
|----------------|------------------|---------------------------|--------------|--------------|
| Communications | 25%              | 51.4%                     | 23.6%        | 100%         |
| Monitoring     | 57.1%            | 42.9%                     | —            | 100%         |
| Residential    | 22.7%            | 48.5%                     | 28.8%        | 100%         |
| Water Pumping  | 35.3%            | 64.7%                     | —            | 100%         |

\*n = 11, Data based on years 1985-86 and 1987-88.

respectively. With respect to monitoring/sensing applications, batteries account for 57.1% of the BOS revenues whereas power conditioning accounts for 42.9% of the total BOS revenues. The profile of BOS revenues for residential applications is similar to communication applications e.g., power conditioning accounts for 48.5% of the BOS revenues, batteries account for 22.7% of the BOS revenues and other items account for 28.8% of the BOS revenues. The waterpumping application's BOS revenues accrue mainly from power conditioning (64.7%) and to a lesser extent from batteries (35.3%). The distribution of BOS revenues for retail and other applications indicates that power conditioning accounts for a major portion of the revenues 54.7% followed by other equipment (36%) and batteries (9.3%).

The information provided by survey respondents on sales of BOS could also be examined from an applications perspective. Exhibit II-5 provides distribution of annual revenues for balance of systems sales by application. The percentage distribution indicates that residential and remote lighting applications account for a major portion of the sales of batteries (40%) followed by retail and other applications (28%) and communications applications (20%). The distribution of power conditioning sales by applications is somewhat different in that retail and other applications account for the highest proportion of sales (55.4%) followed by residential/remote lighting (25.7%) and communications applications (13.5%).

The distribution of BOS annual sales on an aggregated basis (i.e., sum of batteries, power conditioning and other equipment) was also studied. This distribution indicates that retail and other applications account for 50.67% of BOS annual sales, residential and remote lighting applications account for 31.76%, communications applications account for 12.84%, waterpumping applications account for 3.38%, and monitoring/sensing applications account for 1.35%.

### ***The Size of Commercial Activity in the Year 2000***

The respondents to the qualitative survey (results discussed in Chapter III) have estimated the size of the industry in the year 2000 to be in the order of 40 to 50 million dollars provided that the industry and government follow the directions/advice provided by them especially in terms of niche marketing, extensive Canadian trials in northern and remote areas, focus on applications such as solar communications and monitoring, PV/diesel hybrid applications, PV pumping systems, remote and rural lighting etc., and export orientation using a sound information package to potential users in other countries, (please see Chapter III for details).

**EXHIBIT II-5**

**DISTRIBUTION OF ANNUAL\* REVENUES FOR BALANCE OF SYSTEMS SALES  
BY APPLICATION**

|                                | <b>Batteries</b> | <b>Power Conditioning</b> | <b>Other Equipment</b> |
|--------------------------------|------------------|---------------------------|------------------------|
| Communications                 | 20%              | 13.5%                     | 8%                     |
| Monitoring/Sensing             | 4%               | 1.4%                      | —                      |
| Water Pumping                  | 8%               | 4%                        | —                      |
| Residential/Remote<br>Lighting | 40%              | 25.7%                     | 38%                    |
| Retail and Other               | 28%              | 55.4%                     | 54%                    |
|                                | <hr/>            | <hr/>                     | <hr/>                  |
| <b>TOTAL</b>                   | <b>100%</b>      | <b>100%</b>               | <b>100%</b>            |

\*n = 11, Data based on years 1985-86 and 1987-88.

The respondents to commercial activity survey also provided qualitative information on research, market and policy trends. Their opinions are merged with those of respondents to the qualitative survey described in Chapter III.

It should be mentioned here that most of the commercially active participants in the PV industry are of the opinion that the future for the PV industry is strong. The key factors mentioned as being responsible for a healthy and viable future for the PV industry in Canada include:

- Rise in oil prices.
- Increased environmental concerns and the need for PV applications which do not increase pollution.
- Better PV system reliability.
- Strong need for rural electrification programs and PV system in developing countries.

# *III - Findings of Qualitative Survey on Trends*

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Chapter II primarily described the current performance of the photovoltaic industry. However, from a strategic planning perspective, it is more important to focus on the future of the industry. In this chapter, we summarize the opinions of the respondents to the qualitative survey, as well as the responses to Part III of the commercial activity survey.

These surveys aimed at obtaining information on:

- The relevance of world-wide research trends and technological options to the Canadian PV industry.
- The role of the Canadian Government in supporting PV research and development.
- The key market trends pertaining to applications with high growth potential and their relevance to Canada.
- Proactive measures to be adopted by the Canadian PV industry participants.
- The role of public policy in supporting Canadian PV industry.
- Export markets for Canadian PV applications and products.
- The role of public policy in promoting export opportunities.

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## ***Research Trends and Technological Options***

The literature review results (presented in detail in Chapter IV) indicate that there are two major world trends pertaining to the focus of PV research:

- Nearly two-thirds of PV research talents are directed toward amorphous silicon.
- Europe continues to work on polycrystalline silicon cells.

The majority of participants (72%) to our qualitative survey<sup>1</sup> (on world research, price and market trends, and their relevance to the Canadian PV industry and public policy) indicated that the above-mentioned world trends are of relevance to Canada for the following reasons:

- Even if Canada does not concentrate its efforts on cell production, it should definitely closely watch the improvements in cell technology in order to keep our PV systems as advanced as possible.
- Canada should remain knowledgeable on thin-film silicon technology advances in order to compete in world markets.
- The cost reduction resulting from these technological advances will affect the price of imported components used by the Canadian PV industry in its manufacturing, assembling, distributing, and installation activities.

In summary, the responses indicated that even though the Canadian PV industry is not cell-based, the results of advances in thin-film technology will help Canadian industry lower its cost and produce PV systems which can compete in world markets. It was felt that the PV experts in Canada should study these trends and use state-of-the-art technologies.

#### **Role of the Canadian Government in Supporting PV Research and Development**

All respondents to the qualitative survey pertaining to technology, market trends, and policy considerations unanimously agreed that the Canadian government should support applied research in photovoltaics. This means that the government should work closely with the PV industry in product development, testing, evaluation, and marketing. Such an approach will help the Canadian industry to develop unique products for niche markets in the world. The majority of components for the products will be imported; once again, the Canadian government could assist the industry to test and evaluate imported components so that the most cost-effective and state-of-the-art components are used in Canadian PV systems. Some respondents (28%) suggested that the government, while primarily supporting applied research, should also, to a smaller extent, support pure research (fundamental research). This will promote a small but highly renowned knowledge base in Canada in

<sup>1</sup> n = 12

specific areas complementary to our nation's applied Research and Development activities in photovoltaics

### ***Market Trends***

The literature review results on world-wide market trends indicate that consumer products, communications, and PV/diesel hybrid applications will experience tremendous growth during the next decade. Respondents were asked to comment on these worldwide market trends. A great majority of respondents (91%) agreed that these trend projections are reasonable and some have already set in. Consumer products with amazing use of PV technology are already appearing; similarly, new applications in communications such as PV-based cellular telephones indicate a strong segment for the PV industry. Lastly, PV/diesel hybrid applications are extremely valuable and are being used in all parts of the world including the U.S.A.

The respondents to the survey rated the expected growth of various applications. The results shown in **Exhibit III-1, overleaf**, indicate that the highest growth levels are expected in the PV/diesel hybrid applications, followed by communication applications and consumer products. The off-the-grid rural and off-the-grid residential applications are expected to grow at a medium pace. The central station and grid-connected-residential applications are expected to show low growth rates. The expectations of these respondents are identical with the results of the literature review discussed in the next chapter.

The qualitative survey also elicited the opinion of respondents with respect to applications for which they saw high opportunities for growth in Canada. The results are presented in **Exhibit III-2, overleaf**. The results indicate that PV/diesel hybrid applications and communication applications present great opportunities in the Canadian market. Since these applications are also expected to grow in world-wide markets for photovoltaic, it appears that the Canadian photovoltaic industry should gear up to develop innovative products using these applications. The off-the-grid rural and off-the-grid residential markets also present sound opportunities to Canada whose rural dispersion and northern remote locations provide excellent testing grounds for applications which could be spun off to both northern countries in the world and developing countries with a high proportion of rural population.

The consumer products market, despite the possibility of high growth in world markets, is only expected to provide medium level opportunities for the

### **EXHIBIT III-1**

#### **PV APPLICATIONS RANKED BY EXPECTED WORLD-WIDE GROWTH**

| <b>APPLICATIONS</b>        | <b>RANK</b> |
|----------------------------|-------------|
| PV/Diesel Hybrid           | 1           |
| Communications             | 2           |
| Consumer Products          | 3           |
| Off-the-grid Rural         | 4           |
| Off-the-grid Residential   | 5           |
| Central Station            | 6           |
| Grid-connected Residential | 7           |

### **EXHIBIT III-2**

#### **PV APPLICATIONS RANKED BY EXPECTED GROWTH IN CANADA**

| <b>APPLICATIONS</b>        | <b>RANK</b> |
|----------------------------|-------------|
| PV/Diesel Hybrid           | 1           |
| Communications             | 2           |
| Off-the-grid Rural         | 3           |
| Off-the-grid Residential   | 4           |
| Consumer Products          | 5           |
| Grid-connected Residential | 6           |
| Central Station            | 7           |

Canadian photovoltaic industry because of entrenched competition from Japan and the Pacific-Rim countries.

### **Proactive Measures to be Adopted by the Canadian PV Industry**

The respondents to the qualitative survey also indicated that while communications, PV/diesel hybrid applications, remote area applications in lighting, etc., present tremendous opportunities, the Canadian PV industry should adopt the following proactive measures in order to take advantage of these opportunities:

- The industry's R&D should be sufficiently focused on developing unique products suitable for specific environments such as the Northern and Rural areas.
- Components to the products should be allowed to be imported or to be obtained from Canadian sources.
- The federal government should be sold on using PV applications to provide incentive to the industry and at the same time save its own costs.
- Market information should be made available on world market opportunities.
- Improved communications should be provided between researchers, developers, product assemblers, manufacturers, government departments and agencies, (e.g., Export Development Corporation, CIDA) as well as private sector companies.
- Improved testing and demonstration facilities should be made available.
- The industry should actively participate in world PV forums to demonstrate and market its special applications.
- Major efforts should be made to disseminate information on Canadian PV products to the public and private sector users in Canada and the world markets.
- A central registry should be available to provide reference to PV applications, evaluation of the outcomes of these applications, etc.

- CIDA contracts must be pursued more actively with greater ingenuity.
- An overall strategic plan should be developed by industry participants and associations to provide directions for R&D, product development, and marketing efforts.

### **Role of Public Policy In Supporting Canadian PV Industry**

The respondents to the qualitative survey on PV industry trends provided a series of action items in terms of public policy. Their advice to the Department of Energy, Mines and Resources included a number of items described in the ensuing paragraphs.

Two respondents suggested the development of a strategic framework in consultation with the industry. This framework, when developed, would provide a road map to the Canadian PV industry. It would be based on a thorough understanding of world-wide trends in PV and an examination of the strengths and weakness of the Canadian PV industry in view of competition from other countries. Lastly, an analysis would be undertaken to identify market niches which would provide Canada with a competitive edge in world market. Once the niches are identified and agreed upon by the government and industry, public policy should provide support for efforts addressing the select niches.

The respondents also indicated that the international markets are large and in order to obtain a good share of these markets the government should analyze the market requirements of the various markets and target on those that meet the strengths of the Canadian PV industry. The Export Development Corporation, the Canadian Commercial Corporation, and CIDA could all play a significant role in promoting the Canadian PV industry's share of world markets.

According to the respondents, government should fund R&D supportive of applications valuable to the niche markets identified in the strategic plan. Furthermore, by buying Canadian (as in the early 1980's), the Departments of Defense, Northern Affairs, Environment, and the Canadian Coast Guard could all help in spawning new PV applications. The government buildings in northern and remote areas could serve as demonstration sites for PV applications.

Survey respondents also suggested support for Canadian PV applications in the form of tax incentives to the private sector. If these tax incentives are of the right magnitude, then one could envisage the private sector companies such as Bell Cellular supporting the Canadian PV applications.

The market awareness of photovoltaic applications seems very low. The respondents, therefore, stated that both the government personnel and the public should be educated about the advantages of PV applications. Specifically, the value of PV in reducing environmental pollution should be stressed. Test sites and demonstration sites should be developed and this would increase the visibility of PV applications.

The international awareness of Canadian PV applications appear rather low. The respondents indicated that the government could participate in international forums and inform international users about the Canadian experience in PV applications. However, this cannot be accomplished unless, as suggested earlier, the government promotes PV applications via government-sponsored demonstration projects and an active "buy Canadian PV" policy.

Other public policy measures mentioned by a few respondents included continuation of standards work and promotion of Canadian test labs.

#### **Size of Canadian PV Market in the Year 2000 and Now**

If the Canadian government implemented the various policies suggested, the respondents to the qualitative survey estimated the size of the industry in the year 2000 to be in the order of 40 to 50 million dollars.\* This estimate was made by the respondents on the basis of the assumption that today the Canadian PV market is 10 million dollars\* worth and has a power output of 300 KWp.\*

#### **Export Markets for Canadian PV Applications/Products**

The qualitative survey asked industry participants to compare the cost, performance, and quality of Canadian PV products and services with those of other countries. The responses indicate that modules are at least 150% of international market prices and batteries are about 110 - 120% of world prices.

\* Average of respondents' estimates.

In terms of quality, most respondents were of the opinion that services were of good quality; however, the scope of these services were limited. In terms of products, respondents felt that some excellent products were developed but did not survive because of lack of market acceptance. Today, very few advanced Canadian PV products are available. Many of the "commercial" products are just advanced prototypes.

In spite of the lack of a range of services and products, the respondents to the survey felt that the expertise of the Canadian PV industry in communications, remote lighting, and pumping (PV/diesel hybrid) applications is worthy of world markets. The major export markets identified included Africa, Northern Countries, South East Asia, Caribbean, Polynesia, Central America, U.S.A., and Europe. The export trade profile of U.S.A. (described in Chapter IV) is somewhat similar; however, the Canadian PV industry seems to accord higher export potential for Northern Countries, South East Asia, and Africa.

### **The Role of Public Policy in Promoting Export Opportunities**

The qualitative survey asked the survey respondents to describe, what, if anything, could be done by the government to help industry take advantage of export opportunities.

All respondents indicated that the industry liaison officers at Canadian embassies should be informed of the Canadian PV initiatives and applications and asked to look for market opportunities. Furthermore, demonstration modules could be set up at some key embassies to provide visibility to the Canadian PV applications. As stated earlier, Canadian government and industry should present papers in international PV forums. Lastly, CIDA should be encouraged to actively look for renewable energy projects, specifically photovoltaic projects.

In conclusion, this chapter indicates a strong and vibrant Canadian PV industry for the future despite the fact that it is still embryonic.

# *IV - International Markets and Trends - A Literature Review*

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## *Introduction*

The photovoltaic industry has gained prominence throughout the world. Technological advances during the past 10 to 15 years have made many more applications of photovoltaic cells feasible and cost competitive. Today, at least 500 companies in the world are engaged in some activity related to photovoltaic research, manufacturing, system integration and marketing.

This is a brief review of the relevant and recent literature on the international photovoltaic market. Its major focus is on trends relating to: technology and price; market developments and size; and public sector policy. Since the bulk of the literature reviewed originated in the U.S. (most non-U.S. literature is either unavailable or not in English) the trends reported in this review primarily reflect the thinking of U.S. specialists on the worldwide photovoltaic markets.

## *Technology and Price Trends*

Currently, there are five key types of photovoltaic systems in which silicon is the principal energy conversion material used. These are called single crystal silicon, poly-crystalline silicon (cast ingot), ribbon/sheet, concentrators, and amorphous silicon-based modules.

The **single crystal** growing techniques which are in use produce the highest efficiency cells. The **poly-crystalline** silicon cells are approaching the efficiency of single crystal cells and also have excellent lifetimes. More research is being undertaken to produce better poly-crystalline silicon cells. The most efficient method of producing silicon cells involves the spraying of thin films of **amorphous silicon** on a substrate. With respect to amorphous silicon, more research is needed to prevent the photo current from

recombining on impurities. The concentrators which optically focus sunlight onto a small area are very popular in strong sunlight areas such as the Southwestern U.S. The silicon ribbon sheet is in pilot promotion at Westinghouse and Mobil. Of the above technologies, more and more research is concentrated on amorphous silicon.

U.S., Europe and Japan are all involved in research pertaining to amorphous silicon. It is estimated that nearly two-thirds of professional talents in PV research are directed toward improving amorphous silicon producing methods.<sup>1</sup> The technologies used by the various U.S. manufacturers are shown in Exhibit IV-1, overleaf. Despite the emphasis on amorphous silicon research, there is a strong indication that the European firms will continue to work on polycrystal and single crystal cells. Wacker and Siemens lead this field and have a joint venture with Kyocera in Japan.

The research into high purity silicon is closely related to the long-run viability of the photovoltaic industry. It is hoped that research will lead to reduced silicon wafer costs, greater efficiencies in the conversion of sunlight to electricity, advances in the state-of-the-art cell and lower production costs. Increased efficiencies together with lower production costs are critical factors in lowering the market competitiveness of PV systems.

Maycock<sup>2</sup> summarizes the various factors which will lead to cost reductions. These are:

- cell efficiency
- the reduction in pure silicon used due to ribbon processes and advanced slicing
- use of automation
- large area continuous processing in the amorphous silicon area.

The results of Maycock's price analysis, which in turn is based on the Jet Propulsion Labs' assumptions and software, are shown in Exhibits IV-2 and IV-3, overleaf. Exhibit IV-2 indicates that concentrators and amorphous silicon modules will remain the most cost competitive through to the year 2000, with an average price of \$1.66/Watt peak (1987 U.S. dollars). In the year 2000, the silicon ribbon sheet costs, which depend on production

<sup>1</sup> Frost and Sullivan, Photovoltaic Market in the U.S., July 1985.

<sup>2</sup> Paul D. Maycock, Photovoltaic Technology, Performance, Cost and Market Forecast to 2000, 1988.

**EXHIBIT IV-1**

**TECHNOLOGIES APPLIED BY MANUFACTURERS IN THE U.S.**

| <b>Technology</b>                      | <b>Manufacturer</b>                                     |
|----------------------------------------|---------------------------------------------------------|
| <b>Single Crystal</b>                  | Arco Solar<br>Silicon Sensor<br>Solec Int'l<br>Tideland |
| <b>Poly-Crystal</b>                    | Solarex                                                 |
| <b>Amorphous Silicon</b>               | Arco Solar<br>Chronar<br>Solorex<br>Sovonics            |
| <b>Concentrator</b>                    | Entech<br>Intersol                                      |
| <b>Dendritic Ribbon<br/>EFG Ribbon</b> | Westinghouse<br>Mobil Solar                             |

**SOURCE:** M.J. Blanco, **Photovoltaic Export Trade of the U.S.A.**, Solar Trade International, 1987.

**EXHIBIT IV-2**

**ACTUAL AND PROJECTED**

**AVERAGE PRICE OF SILICON-BASED OPTIONS**

**(Constant 1987 U.S. Dollars Per Peak Watts)**

| <b>Modules/ Silicon Options</b> | <b>1987<br/>Price (\$/Wp)</b> | <b>1990<br/>Price (\$/Wp)</b> | <b>1995<br/>Price (\$/Wp)</b> | <b>2000<br/>Price (\$/Wp)</b> |
|---------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| A. Ribbon (Sheet)               | 7.50                          | 5.00                          | 3.50                          | 3.33                          |
| B. Single Crystal               | 5.40                          | 4.0                           | 3.50                          | 2.50                          |
| C. Polycrystal                  | 5.40                          | 3.50                          | 3.00                          | 3.33                          |
| D. Concentrators                | 5.00                          | 3.00                          | 2.00                          | 1.66                          |
| E. Amorphous Silicon            | 5.00                          | 2.50                          | 2.00                          | 1.66                          |
| <b>Average (\$/Wp)</b>          | <b>5.50</b>                   | <b>3.50</b>                   | <b>2.50</b>                   | <b>2.00</b>                   |

**SOURCE:** Paul D. Maycock, *Photovoltaic Technology, Performance, Cost and Market Forecast to 2000*, 1988.

### EXHIBIT IV-3

#### COMPARISON OF REMOTE SYSTEM (1KW) AND LARGE SYSTEM (1-10 MW)

#### INSTALLED COSTS PER KWp AND WP

(Constant 1987 U.S. Dollars)

|              | 1987   |       | 1990   |       | 1995   |       | 2000   |       |
|--------------|--------|-------|--------|-------|--------|-------|--------|-------|
|              | Remote | Large | Remote | Large | Remote | Large | Remote | Large |
| Module       | 7,000  | 5,000 | 5,000  | 4,000 | 3,000  | 2,000 | 2,000  | 1,500 |
| Battery      | 2,000  | 500   | 1,500  | 400   | 1,500  | 200   | 1,500  | 150   |
| Wiring       | 100    | 500   | 50     | 300   | 50     | 200   | 50     | 150   |
| Labour       | 1,500  | 1,000 | 1,000  | 800   | 800    | 500   | 500    | 300   |
| Total \$/KWp | 10,600 | 7,000 | 7,550  | 5,500 | 5,350  | 2,900 | 4,050  | 2,100 |
| Total \$/Wp  | 10.60  | 7.00  | 7.55   | 5.50  | 5.35   | 2.90  | 4.05   | 2.10  |

**SOURCE:** Paul D. Maycock, Photovoltaic Technology, Performance, Cost and Market Forecast to 2000, 1988.

quantities, will still be higher compared to amorphous silicon, concentrators, and poly-crystalline silicon modules. The single crystal module costs are expected to be identical to those of ribbon sheet modules in the year 2000.

On the average, based on price trends for various module types, Maycock expects the prices, in constant 1987 U.S. \$/Wp, to decline from \$5.50 in 1987 to \$3.50 in 1990, to \$2.50 in 1995 and to \$2.00 in 2000. Exhibit IV-3 indicates that the installed costs of PV systems differ depending on the type of system. The remote systems (1kW), generally used at telecommunications relay sites, portable water pumping, cathodic protection, irrigation, refrigeration and desalination, have higher installed costs than the large systems (1-10 MW) used in central power. Maycock indicates that remote site system costs will drop from \$10.80/Wp in 1987 to \$4.05/Wp in the year 2000. This forecast is generally similar to the conservative estimates of systems prices provided by Commission of the European Economic Community in 1982 and Polydyne Inc.,<sup>3</sup> at the EEC conference.

### ***Market Trends***

The overall trends in the photovoltaic industry suggest a strong market in the future.<sup>4,5</sup> The 1988 production capacity of the 9 major manufacturers of amorphous silicon in the worldwide market ranges from 15-18 MW and is expected to reach 43-50 MW by 1990. These major manufacturers (Arco, Sanyo, Fuji, Chronar, Solarex, Sovonics, Glasstech Solar, Kaneka and Taiyo Yuden) are fully aware of the fact that for significant market penetration to occur, amorphous silicon modules must become more efficient, more reliable and more cost-effective (\$3 per Watt or less).

It is encouraging to note from the literature that progress towards a stronger PV industry has occurred despite some depressing trends in the economic and political environment such as declining oil prices, oversupply of natural gas in the U.S., and failure of the U.S. congress to extend tax credits for solar energy.

The market forecasts developed by Maycock appear to provide a realistic range under two scenarios. The first, called the "Business as Usual" scenario, makes several status quo assumptions. For example, oil prices remain in the \$12-22 per barrel range, the policies of governments do not change, fewer, if

<sup>3</sup> From appendices to Maycock's report.

<sup>4</sup> M.J. Blanco, *op. cited*.

<sup>5</sup> Post, H.N. and Thomas, M.G., "Photovoltaics Systems for Current and Future Applications", *Solar Energy*, Vol. 41, No. 5, pp-465-473, 1988.

any, tax credits are available and there is no serious oil shortage. The "accelerated" market scenario assumes escalating oil prices at 2-3 percent per annum, a new administration in the U.S. with a long-term energy strategy, and a greater concern for environmental pollution and safety.

The projections made under both these scenarios are more conservative, and appear far more reasonable, than forecasts made by other authors in the early and mid 1980's. The Maycock study also seems to have more validity because it takes into account the forecasts of most authors and government agencies, and sometimes explains the reasons for differing from these forecasts.

This review draws heavily from Maycock for market forecasts by technology. The market trends in each market sector by application are, however, drawn from a variety of sources. The projections for the different market segments described below are summarized in Exhibit IV-4, overleaf.

### **Consumer Products**

This market sector has a variety of applications in consumer electronics, watches, calculators, radios, LCD display, clocks, thermostats, etc. Some higher power applications include rechargeable tools, drills, weed eaters and clippers. In this market the price elasticity of demand is very high. Based on the technology forecasts and the price of silicon modules, some manufacturers like Sanyo project the market demand to be 60-80 MWp for such applications by the year 2000.

### **The Central PV Generation Market**

Growth in this market sector did not meet the expectations of various earlier forecasts. Several major projects and production plants were cancelled in the U.S., e.g., the SMUD (Sacramento Municipal Utility District) project, and the Solarex and Intersol plants. It appears that cost reduction and high volume sales are necessary for PV to grow significantly in this sector. Also, tax credits for "third party financing" seem to be a very important prerequisite for growth.

The economics of central PV in 1988 is analyzed by Maycock who gives the following cost summary based on extensive research:

- installed system cost - \$7.00/W
- system warranty 5 years, 90% performance at 2500 Wh/year

# EXHIBIT IV-4

## WORLDWIDE MARKET FORECASTS

### FOR PV MODULES IN MWp

"BUSINESS AS USUAL" SCENARIO<sup>(I)</sup> VS. "ACCELERATED SCENARIO"<sup>(II)</sup>

| Sectors                    | 1984      |           | 1985        |           | 1987        |           | 1990      |           | 1995       |            | 2000       |           |
|----------------------------|-----------|-----------|-------------|-----------|-------------|-----------|-----------|-----------|------------|------------|------------|-----------|
|                            | I         | II        | I           | II        | I           | II        | I         | II        | I          | II         | I          | II        |
| Central Station            | 2         | 2         | 2           | 2         | .5          | .6        | 4         | 4         | 5          | 10         | 10         | 10        |
| Consumer Products          | 6         | 6         | 7           | 7         | 10          | 10        | 30        | 40        | 50         | 70         | 60         | 8         |
| Off-the-Grid Residential   | 2         | 2         | 2           | 2         | 2           | 2         | 4         | 8         | 10         | 20         | 20         | -         |
| Off-the-Grid Rural         | 3         | 3         | 3           | 3         | 4           | 4         | 6         | 4         | 8          | 15         | 20         | -         |
| Grid Connected Residential | .1        | .1        | .1          | .1        | .1          | .3        | .5        | 1         | 1          | 5          | 5          | 2         |
| Communications             | 6         | 6         | 8           | 8         | 10          | 10        | 20        | 20        | 30         | 40         | 40         | 6         |
| PV/Diesel Commercial       | 3         | 3         | 4           | 4         | 5           | 5         | 5         | 10        | 20         | 50         | 40         | 10        |
| <b>Total (MWp)</b>         | <b>22</b> | <b>22</b> | <b>26</b>   | <b>26</b> | <b>32</b>   | <b>32</b> | <b>70</b> | <b>87</b> | <b>124</b> | <b>210</b> | <b>195</b> | <b>44</b> |
| <b>Price (\$/Wp)*</b>      | <b>7</b>  |           | <b>6.50</b> |           | <b>5.50</b> |           | <b>4</b>  |           | <b>3</b>   |            | <b>2</b>   |           |

I - "Business as Usual" or status quo scenario assumes no change in oil prices and that tax credits are not available.

II - "Accelerated Scenario" assumes escalating oil prices and long-term energy strategy in the public sector.

\* Dollars are 1988 U.S. dollars

**SOURCE:** Paul D. Maycock, Photovoltaic Technology, Performance, Cost and Market Forecast to 2000, 1988.

- annual AC Electricity per peak Watt - 2200-2600 Wh/W of capacity
- annual value of electricity \$.25
- O&M cost per Watt/year - \$.02
- system life 20 years.

Given the above, an investment of \$7 per watt yields \$.25 per year worth of electricity and is, therefore, not economically viable for base loads. Unless installed system costs drop to \$2.50 per watt, such a PV application will not be attractive. However, some growth could be achieved by penetrating those utilities which still burn oil for peaking and intermediate electricity. Some forecasts suggest 100 MW/year PV sales from this strategy.

The U.S. Department of Energy (DoE) plan of 1986 assumes lower costs in its projections for central station PV. Based on the dependence on oil, gas and nuclear generation, five U.S. states offer the best target opportunities for PV. These five are California, Florida, Hawaii, Arizona and New Mexico which, collectively, form the U.S. sunbelt market.

Based on the projected economic situation, government incentives, and current factors in specific markets in the U.S., the central station PV market is expected to reach 10 MW under the "business as usual" scenario (no oil price escalation, not many tax credits) and 100 MW under the accelerated scenario (oil prices escalate, government supports PV) in the year 2000. The accelerated scenario is not very likely to occur (with less than a 30 percent chance according to Maycock).

### **Off-the-Grid Residential and Rural Markets**

The off-the-grid-residential market sector appears promising in the U.S. and has expectations to serve 1 million houses without electricity, 3 million motor homes, 2 million live-in boats and house boats and 20 million campers. The U.S. market appears critical for the world market. At a price of \$2/Watt by the year 2000, the market in U.S. will reach a size of 20 to 40 MW.

The off-the-grid international market is primarily rural. The market has been strong in Spain, Southern France, Italy and Scandinavian countries. Village community centers are becoming quite popular. India has a large projected market for off-the-grid rural PV. There is a solid market, though

limited in size, for small off-the-grid stand-alone systems for lighting, entertainment and refrigeration<sup>6</sup>. This market would grow at higher rates if more information on PV systems is made available to potential customers. However, current profit margins cannot sustain higher marketing costs. On the other hand, if governments encourage this market through R&D and financing, PV systems could penetrate the segment at higher than expected rates.

The world market for off-the-grid rural PV could be 15 to 40 MW by the year 2000. A large number of international markets are likely to assume local assembly and partial production responsibilities within this time frame.

### **Grid Connected Residential Market**

The economics in this market sector are complicated. The U.S. is the largest user of this technology. The DoE supported about 30 experiments in grid connected houses. The experiments demonstrate that PV systems can perform as designed, although mounting schemes need improvement to keep the cells cool. The experiments also indicate that there are no code barriers to PV systems, financing will be available, and that PV systems could be insured. However, unless installed costs go down to \$2-3 per W, this market will not take off. At these price levels, 5 to 20 MW of PV is likely in this market segment by the year 2000.

### **Communication/Signal Market**

This market sector has significant worldwide potential. PV applications for powering microwave repeaters, TV translators, radio telephones, educational TV, mobile radios, remote signalling, and telemetry have proven to be reliable and economic.

The U.S. and other international markets look promising for the PV communications sector. Saudi Arabia, Egypt and Kuwait have used PV for communications. Latin American users have implemented PV for establishing communication links with villages. Venezuela and Ecuador will follow suit. In Asia, large potential exists in India, Pakistan, Thailand and Indonesia. In Africa, the Post and Telegraph of South Africa has used PV. If the African economy improves, there will be more demand for communications-related PV applications. Tanzania, Kenya, Nigeria and Sudan show promise as PV markets for telecommunication applications.

<sup>6</sup> Post, H.N. and Thomas, M.G., op-cited.

The overall communications market is forecast at 40 to 60 MW in the year 2000. This forecast appears to be very achievable.

As reported by Photovoltaic Insiders' Report, a recent Frost and Sullivan study (1987) has forecast the rural electrification, cathodic protection, telecommunications and related remote site markets to be in the order of 73 MW by the year 1992.<sup>7</sup>

### **PV/Diesel Hybrid Market**

The diesel or gasoline generator can be used as the storage for a PV system. The world diesel market is primarily in the Middle East for applications such as water pumping, provision of electricity for small houses, community centers, etc. This market segment overlaps with the off-the-grid rural market segment. The replacement market is further segmented by the size of diesel engines, e.g., 5KW and under, 6 to 20 KW and between 21 and 100 KW. With a projected module price of \$2.50/W and a system price of \$4-5 W, the market demand in this sector in 1990 is projected at 40 to 100MW. The wide range is used to cover uncertainties in the worldwide economics.

### **Relative Strengths of Various Markets**

A report entitled "Photovoltaic Export Trade of the USA" (Solar Trade International) provides data on U.S. exports to the world. The reports (1985-1987) are useful in that they indicate the trends in the U.S. export trade. From the relative level of U.S. exports to the various markets, it appears that Europe and the Far East continue to offer significant opportunities. South Asia and the Caribbean markets are also reported as showing significant growth. Exhibit IV-5, overleaf, summarizes the U.S. export trade in PV to various countries for the years 1984 to 1987.

### **Market Trends Summary**

The above examination of worldwide markets for the various sectors captures the key trends described in the literature. The forecast numbers from Maycock are used because they best describe the impact of the "status quo" scenario and the "accelerated scenario". Secondly, case studies and extensive cost analyses support these forecasts. These include the Frost and Sullivan reports (1981 and 1985), which we reviewed to compare the various forecasts. In our opinion, Maycock's forecasts fall within an acceptable range and

<sup>7</sup> This report on remote site power markets was not purchased since other reports were known to refer to its key projections.

**EXHIBIT IV-5****DISTRIBUTION OF U.S. TOTAL PHOTOVOLTAIC  
EXPORT SHIPMENTS BY WORLD REGIONS**

| <b>Region</b>                   | <b>1984<br/>% Total Exports</b> | <b>1985<br/>% Total Exports</b> | <b>1986<br/>% Total Exports</b> | <b>1987<br/>% Total Exports</b> |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Europe                          | 40.9                            | 46.9                            | 30.9                            | 40.2                            |
| Far East                        | 17.8                            | 16.7                            | 23.2                            | 20.6                            |
| Oceania                         | 4.3                             | 8.3                             | 3.7                             | 7.5                             |
| Africa                          | 9.7                             | 7.1                             | 9.8                             | 8.2                             |
| Middle East                     | 5.7                             | 6.8                             | 5.6                             | 6.7                             |
| North America                   | 5.1                             | 5.9                             | 11.0                            | 5.1                             |
| South East Asia                 | 9.1                             | 5.5                             | 5.6                             | 5.8                             |
| South America                   | 4.5                             | 2.0                             | 7.9                             | 3.9                             |
| South Asia                      | 0.7                             | 0.5                             | 1.4                             | 1.0                             |
| Caribbean                       | 2.3                             | 0.4                             | 0.8                             | 1.0                             |
| <b>Total %</b>                  | <b>100.0%</b>                   | <b>100.0%</b>                   | <b>100.0%</b>                   | <b>100.0%</b>                   |
| <b>Total Exports</b>            | <b>2.3 MW</b>                   | <b>2.9 MW</b>                   | <b>3.2 MW</b>                   | <b>3.8 MW</b>                   |
| <b>Average Prices (Cells)</b>   | <b>\$6/Watt</b>                 | <b>\$5/Watt</b>                 | <b>\$4/Watt</b>                 | <b>\$3/Watt</b>                 |
| <b>Average Prices (Modules)</b> | <b>\$8/Watt</b>                 | <b>\$7/Watt</b>                 | <b>\$6/Watt</b>                 | <b>\$5/Watt</b>                 |

**SOURCE:** M. J. Blanco, Photovoltaic Export Trade of the U.S.A., Solar Trade International, 1985, 1986 and 1987.

provide a reasonable profile for the worldwide market demand for PV. This view is consistent with some EEC projections and the economics reflected in U.S. Department of Energy publications.

### ***Public Sector Policy Trends***

The public sector is a major player in the photovoltaic power system market. Governments in Canada, Japan, Europe and the U.S. have assisted in promoting the photovoltaic industry. The main initiatives taken by these governments in the past are summarized below. Also, a brief discussion of the key areas for future government involvement is provided.

#### **Canada**

In the Canadian PV market, the public sector, and the federal government in particular, is involved in a variety of ways,<sup>8</sup> for example:

- In the years 1982-1984, the government stimulated demand by using at least 40% of photovoltaic power generated.
- The government also provided significant support for Research and Development activities.
- Import duties have been exempted on some photovoltaic modules for end-uses such as navigational aids.

Despite this involvement in the past, the Ontario Ministry Report states that a more strategic approach to photovoltaics is necessary. The overall objectives of an Energy Program should be translated into sub-objectives for various renewable energy forms and, in this context, the role of photovoltaics should be studied. Since PV research requires a significant amount of resources before any breakthrough is accomplished, the government should make a decision on the level of effort it can afford for PV R&D and, secondly, should examine the sufficiency of this level of effort for specific initiatives. A cost-benefit framework would help to identify the most cost-effective areas for government-funded R&D. Through a strategic approach, the government can examine the relative worth of various promising market segments, such as remote site power, off-the-grid rural applications, and diesel replacement.

<sup>8</sup> Ontario Ministry of Energy, *Assessment of the Canadian Market for Photovoltaic Power Systems*, 1984.

## Japan

The Sunshine Project of Japan has been widely discussed in literature.<sup>9</sup> Recent reports suggest that the Japanese government continues to actively support PV initiatives. The "New Energy Foundation", established under the Sunshine Project, supports investigations of new energy technologies, case studies for economic feasibility, market research, and international cooperative alliances. One of the most important concepts introduced under the program is amorphous silicon solar cell production using an automated assembly line. The program has also fostered a wide variety of application systems developed especially for consumer electronics applications.

## Europe

The photovoltaic power generation program in Europe<sup>10</sup> covers the period 1985-1989. The overall EEC program budget is reported at 20 million ECU. The three major areas of R&D under this program are:

- amorphous silicon solar cells
- thin film solar cells from alternative materials
- photovoltaic pilot program.

This program is somewhat different and less ambitious compared to the earlier (1979-1983) Solar Energy R&D program.<sup>11</sup> The European program also focuses on international alliances, e.g., agreements between Arco Solar and Siemens to start a major amorphous silicon manufacturing facility in Europe. In addition to amorphous silicon, innovations in the poly-crystal area are also interesting development in Europe. The Japanese success in polycrystal ingot technology will be tried by the Wacker/Kyocera joint venture.

## U.S.A.

The U.S. public sector policy toward photovoltaics has been subject to change depending on the administration in power. For example, under the Carter Administration, U.S. government R&D funding stimulated the PV

<sup>9</sup> U.S. Department of Energy, Abstracts, National Photovoltaics Program Annual Review Meeting, 1984.

<sup>10</sup> Commission of the European Communities, Photovoltaic Power Generation R&D Programme, August 1987.

<sup>11</sup> U.S. Department of Energy, Abstracts, op-cited.

industry's sales.<sup>12</sup> President Reagan's shift to use of market forces, together with generous tax credits, led to the construction of larger plants with good economies of scale. In 1985, government funding became scarce. Despite this, the industry self-funded its R&D in the order of \$50 to \$75 million dollars and demonstrated that without government leadership it could still sustain its progress. The current milieu, as reported by Maycock, is one of no tax credits from the Central Administration and the disappearance in many states of support for PV. Even in this scenario (business as usual), the U.S. PV industry looks quite strong. As seen by Post and Thomas (from Sandia National Laboratories), standalone applications for telecommunications, vaccine refrigeration, water pumping, etc., are economically viable and technologically reliable. The central power applications, however, do not appear economically viable in the short run.

The above review of public sector involvement in the various countries indicate that Europe and Japan have a firmer commitment to PV than Canada and the U.S. The U.S. private sector is, however, very independent and seems quite strong.

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## *Conclusions*

It is concluded from the literature review that PV module and installed systems costs will be considerably lower by the year 2000. By that time, given its natural advantages of safety and no pollution, PV technology will be widely adopted for telecommunications, telemetry, cathodic protection, pumping, rural off-the-grid and diesel replacement applications.

The worldwide markets for PV systems are encouraging. The developing nations in South Asia offer tremendous opportunities.

Amorphous silicon technology-related breakthroughs are expected in U.S., Europe and Japan. Europe and Japan have additional joint interests in polysilicon crystals. Government support for PV has wavered in most countries except Europe and Japan.

The literature review indicates that a strategic vision of energy policy is necessary both in the U.S. and in Canada. The U.S. industry has shown that it can survive despite the withdrawal of tax credits. The Canadian industry, however, is too small to sustain itself and may need government support.

<sup>12</sup> Frost & Sullivan Inc., Photovoltaic Market in the U.S., July 1985.

# Appendix A

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## List of Key Literature Contributing to the Literature Review Summary

1. M.J. Blanco, Photovoltaic Export Trade of the U.S.A., 1987.
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# Appendix B

Provisional

## ***List of Photovoltaics Market Literature (Chronological Order)***

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